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Biotic and Physico-chemical Conditions in a
Cooling Reservoir of a Coal-Fired Power Plant

by

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Abstract

Cholla Lake is a cooling reservoir for the coal-fired Cholla electrical generating plant. The lake provides recreational fishing and water contact recreation. The fish populations are self-sustaining.

I collected water, sediment, and whole body fish samples to be analyzed for levels of some possibly toxic inorganic constituents. I also measured dissolved oxygen, pH, Secchi disk transparency. I compared current fish population structure, fish stomach contents, and the frequency of occurrence of benthos, with those same parameters in previous studies.

Water temperature and turbidity have increased; catfish and bluegill have increased in their relative abundance; and the density of benthic invertebrates has decreased. Aquatic insects occur most commonly in the stomach contents of bluegill and filamentous algae in the stomachs of catfish. Selenium levels in all matrices exceed national averages and are above levels in a nearby reservoir unaffected by the power station.

INTRODUCTION

Cholla Lake, Navajo County, Arizona, was constructed in 1961 by the Arizona Public Service (APS) Company as a cooling reservoir for steam turbine generators at the Cholla Power Generating Plant (Dames and Moore, 1973). At present, Cholla Generating Plant has a 615-MW capacity, with two of its generators (115 and 250-MW) cooled by Cholla Lake (Novy 1986). The lake has an area of 138 ha (340 A) and is divided into two portions by an inverted weir; a 36 ha (431,670 m^3) <u>hot</u> pond and a 102 ha (2,040,000 m^3) <u>cold</u> pond. Cooling water is circulated from the cold pond through the plant and into the hot pond at a rate of about 16.0249 m^3/sec. This circulation sets up a thermal gradient throughout the lake; the highest temperature is at the point of discharge and the lowest temperature, at the intake valves. The water temperature ranges from 24.6 C to 40.7 C at the discharge outlet and from 13.0 C to 28.8 C at the intake canal (Novy 1986). About 12,327,480 m^3 (10,000 A-ft), of cooling water is required per year (Dames and Moore 1973). The water level of Cholla Lake is held constant (elev. 1531 m) by the addition of water pumped from the Coconino aquifer (Dames and Moore 1973). The lake has no surface inflow or outflow, and there are no underwater seeps. Cholla Lake provides a locally important recreational fishery (Blinn, et al. 1975, Novy 1986), although the population structure of the predominant species seems to fluctuate erratically (Novy 1986).

The unique conditions in Cholla Lake may have several effects on the biota. The generator boilers are fueled annually with about 4,000,000 tons of sub-bituminous coal (Dames and Moore 1973). Coal, which is similar in composition to the coal used at the Cholla generating station, has an average selenium concentration of 1.59 ppm (std. dev.= 0.30) (Arizona Bureau of Mines 1977). Lemley (1985) reports that large-scale combustion of coal, primarily at steam-electric generating plants, can result in a significant input of selenium to aquatic ecosystems. Selenium has been recognized as being potentially toxic to fish and biomagnification through the food chain can result in chronic toxicity from aqueous levels as low as 10 ppb (Lemley 1985). Lenley (1985) also reports that large-scale combustion of coal, primarily at steam-electric generating plants, could result in a significant input of selenium to aquatic ecosystems. Data from King (1988) indicate that contaminants in a cooling water reservoir in Texas were dispersed throughout the ecosystem, but were concentrated in fish.

Many other metals known to be toxic to aquatic life are also common constituents of coal. These metals include arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, and zinc (Torrey 1978). During the combustion process, these metals volatilize and adsorb to small particles of ash in the exhaust fumes. Although most of these small particles (fly ash) are removed from the exhaust stacks with electrostactic precipitators and water-operated scrubbers, substantial amounts are still released into the atmosphere. The furnaces at Cholla Lake produce about 1,400 tons of ash per day, some of which may escape through the stacks. Precipitation of these particles can cause deposition of inorganic constituents, escpecially metals, in the surrounding environment. Emitted solids from coal-fired plants are the greatest anthropogenic source of particulates to the atmosphere (Goldberg 1985).

High water temperatures are also known to impact aquatic organisms. Whitaker (1977) reported a significant decrease in the numbers of aquatic invertebrates, especially chironomids, with increased temperature. Blinn et al. (1975) clearly demonstrated the importance of benthic organisms as food for fish in Cholla Lake.

Another potential hazard of thermal effluent is that the solubility of oxygen decreases as water temperature increases. The combination of a depleted forage base, high metal levels and a decrease in available oxygen could affect the population structure of fishes, the levels of toxic metals, especially selenium, in fishes, and the presence and abundance of benthic organisms in Cholla Lake.

To assess changes that may have recently occurred in the lake, physio-chemical and biological data gathered at Cholla Lake during my study were compared to data from an earlier study (Blinn et al. 1975). To determine if levels of selenium and other potentially toxic inorganic constituents in Cholla Lake differ from nearby surface waters, a comparison of element levels in water, sediment, and fish tissue was made with Clear Creek Reservoir. Clear Creek Reservoir, west of Winslow, Arizona is similar in size to Cholla Lake. Both lakes lie on a Quaternary sand substrate (Arizona Bureau of Mines 1960), but Clear Creek receives water from surface runoff and is not used for cooling water. Levels of elements in water samples from Cholla Lake were also compared to levels found in water from the well field make-up which is used to keep Cholla Lake filled.

OBJECTIVES:

The objectives of this study are to:

1. Compare levels of selenium and other inorganic contaminants (e.g., As, Hg, Cd, and Zn), in Cholla Lake, Clear Creek Reservoir, and the Cholla Lake well field.

2. Compare length and weight and numbers of fish from Cholla Lake with similar data taken during 1976 studies prior to the addition of the 250-MW generating unit.

3. Compare physico-chemical measurements (e.g., dissolved oxygen, temperature, pH, and Secchi disk transparency), along the thermal gradient at Cholla Lake with previous values.

4. Determine the occurrence of benthic organisms along the thermal gradient at Cholla Lake.

METHODS

Cholla Lake was divided into four sections (A, 1, 2, 3) representing the horizontal thermal gradient. Within each section, samples were taken at 12 points along a transect which was situated perpendicular to the thermal gradient (Fig. 1). Additional water samples were obtained from the Cholla Lake well field inflow pipe.

insert fig 1

Clear Creek Reservoir was not divided into sections because there was no horizontal thermal gradient. One 12-point transect was established along the length of the reservoir.

Samples for chemical analysis (water, sediment, and fish tissue) were collected at each transect two times during the summer of 1989; once in early June and again in late July. Fish lengths and weights were recorded throughout both the summers of 1989 and 1990.

Samples from Clear Creek Reservoir and the Cholla Lake well field were compared to those from the four sections of Cholla Lake. Comparison between Cholla Lake and Clear Creek allowed evaluation of conditions in Cholla Lake relative to those in a surface filled reservoir, and comparisons between Cholla Lake proper and the well field allowed evaluation of conditions before and after water had passed through the power plant.

Collection and Treatment of Samples for Contaminants Analysis

Water

A U.S.G.S. depth integrated water sampler (model U.S. DH-59) was used to collect an individual sample at each point along the transects described earlier. The individual samples from each transect were combined into a composite using a U.S.G.S. churn splitter. Two subsamples were drawn from this composite; one subsample was filtered using a 0.45-um membrane filter, the other subsample was not filtered. Water samples were collected two times from each location on each transect; once at the beginning of the summer and once near the end of summer. All water samples were preserved by acidifying to pH < 2 with nitric acid (H_2NO_3). Water samples from Cholla Lake and Clear Creek Reservoir were analyzed for levels of suspended and dissolved inorganic constituents (Table 1).

Sediments

Sediments were collected using a gravity core sediment sampler fitted with a plastic sleeve. Individual samples were collected at each point along each transect. On two occasions the top 7.6 cm of each individual sample were combined into a 1-l composite. The samples were stored in cleaned jars and were preserved by freezing.

Fish tissue

Channel catfish (Ictalurus punctatus) and bluegill (Lepomis macrochirus) were collected with variegated mesh size gill nets and trammel nets along each transect in

Table 1. ANALYTES AND ANALYSIS TYPES USED FOR ALL SAMPLE MATRICES FROM CHOLLA LAKE AND CLEAR CREEK RESERVOIR, AZ.

ANALYTE		ANALYSIS TYPE	ANALYTE		ANALYSIS TYPE
Aluminum	(Al)	ICP	Lead	(Pb)	ICP
Antimony	(Sb)	ICP	Magnesium	(Mg)	ICP
Arsenic	(As)	AA	Manganese	(Mn)	ICP
Barium	(Ba)	ICP	Mercury	(Hg)	(CV)AA
Beryllium	(Be)	ICP	Molybdinum	(Mo)	ICP
Boron	(B)	ICP	Nickel	(Ni)	ICP
Cadmium	(Cd)	ICP	Selenium	(Se)	AA
Cobalt	(Co)	ICP	Silver	(Ag)	ICP
Chromium	(Cr)	ICP	Strontium	(Sr)	ICP
Copper	(Cu)	ICP	Tin	(Sn)	ICP
Iron	(Fe)	ICP	Vanadium	(V)	ICP
			Zinc	(Zn)	ICP

Cholla Lake and Clear Creek Reservoir. Composite whole body samples of five individuals of each species of the same weight and length were analyzed. Three composites for each species (15 whole body samples) were taken at each transect. Samples were wrapped in aluminum foil and preserved by freezing.

All chemical analyses (water, sediment, and fish tissue) were conducted by a U.S. Fish and Wildlife Service certified laboratory in Patuxent, MD. Selenium, arsenic, and mercury were analyzed with atomic absorption spectroscopy (AA). Boron was analyzed with graphite furnace atomic absorption (GFAA). All other metals were analyzed with inductively coupled plasma emission spectroscopy (ICP) following a pH6 preconcentration.

Results from each transect were recorded as means with standard deviations. Comparisons between transects within Cholla Lake and between treatment (filtered vs unfiltered) were made with one-way ANOVA. Comparisons between Cholla Lake and Clear Creek Reservoir were made with the Wilcoxon-rank sum test. For the purpose of comparison with the National Contaminant Biomonitoring Program average values, dry weight fish tissue results were converted to wet weight values using the equation; wet weight = dry weight [(100 - % moisture)/ 100].

Physico-chemical Measurements

At the 12 points along each transect, surface and bottom temperatures and dissolved oxygen were recorded with a Yellow Springs Instrument Co. Model 54 Oxygen Meter/thermister. Surface water temperatures also were taken along each transect and along the entire length of the lake with a mercury bulb thermometer. The pH was taken at the same 12 locations along each transect with a VWR digital pH meter and water transparency was measured with a Secchi disk. Conductivity was measured using an Industrial Instruments, Inc. model RA-2A conductivity meter. High conductivities of the water (>2000 micromhos/cm), necessitated that I take measurements on diluted water fractions.

The frequency of occurrence of benthic invertebrates was determined using an Eckmann dredge and a U.S.A. Standard Testing Sieve (No.40).

Fish Populations

Fish for population analysis were collected at all sites in Cholla Lake and Clear Creek Reservoir using variegated mesh size gill nets, trammel nets, and minnow traps. Minnow traps were baited with dry dog food and punctured cans of sardines. The frequency of occurrence of each species of fish was compared with similar data reported by Blinn et al. (1975), and Novy and Clay (1986). All fish were weighed (in grams), and measured (in millimeters), and scales were taken from bluegill. Weight and total length were used to calculate proportional stock density (PSD), relative stock density (RSD), condition factors (K_{TL}), and to estimate age classes. Proportional stock density was calculated as No. fish > minimum quality length/ No. fish > minimum stock length (Anderson and Gutreuter 1983). Quality stock sizes were 305 mm for channel catfish and 152 mm for bluegill. Stock sizes were 203 mm for channel catfish and 76 mm for bluegill (Novy and Clay 1986). Condition factor was calculated as $K = 100{,}000\ W_{(g)}/L^3_{(mm)}$. All calculated population indices were compared to those reported by Blinn et al. (1975) and Novy and Clay (1986).

Stomach contents of 10 channel catfish, 10 bluegill, 3 carp, and 3 largemouth bass were preserved in 10% formalin solution. Dietary composition of these stomachs is reported as frequency of occurrence of individual food items.

RESULTS

Water Analysis

There were no significant differences ($p > 0.5$) in concentrations of selenium, mercury, and arsenic in filtered or unfiltered samples within each site , or between the Cholla Lake transects. Arsenic, mercury, and selenium were below detection levels in Clear Creek Reservoir, and mercury was below detection in Cholla Lake proper and the well field (Table 2).

There were no significant differences ($p > 0.5$) in the concentration of 20 inorganic analytes between the filtered and unfiltered samples from Clear Creek Reservoir and the Cholla Lake well field. Many analytes were below detection levels (Table 3). Levels of Al, Cu, Fe, Mn, and Zn in Cholla Lake were significantly higher ($p < 0.001$) in unfiltered samples and levels of Ba, Pb, and Sr were significantly higher ($p <0.005$) at site No. 3. The analytes Sb, Be, Cd, Co, Ag, and Sn were below detection levels in Cholla Lake (Table 4) however, Al, Ba, B, Cu, Fe, Mn, Sr, and V were higher in Cholla Lake when compared to Clear Creek ($0.002 < p < 0.03$).

Table 2. ATOMIC ABSORPTION FOR ARSENIC, MERCURY, AND SELENIUM IN WATER SAMPLES FROM CHOLLA LAKE, CHOLLA LAKE WELL FIELD, AND CLEAR CREEK RESERVOIR. (All values reported in ppm).

	CHOLLA LAKE	CHOLLA LAKE WELL FIELD	CLEAR CREEK RESERVOIR
analyte	(n = 8)	(n = 1)	(n = 2)
As	0.0035 (±0.00045)	0.00063 (±0.00009)	<0.003[1] (±0.00)
Hg (CV)	<0.0002[1] (±0.000)	<0.005[1] (±0.00)	<0.0002[1] (±0.00)
Se	0.0047 (±0.00097)	0.00345 (±0.00015)	<0.003[1] (±0.00)

[1] detection limits.

Table 3. ICP RESULTS FOR WATER SAMPLES FROM CLEAR CREEK RESERVOIR AND THE CHOLLA LAKE WELL-FIELD, AZ. (Reported in ppm).

	CLEAR CREEK (N = 4)		WELL-FIELD (N = 2)	
ANALYTE	MEAN	STDEV	MEAN	STDEV
Al	0.284	±0.347	<0.05[1]	±0
Sb	<0.03[1]	±0	N/A	N/A
Ba	0.0885	±0.01223	0.0094	±0.0004
Be	<0.001[1]	±0	<0.005[1]	±0
B	0.051	±0.00283	<0.055[1]	±0
Cd	<0.001[1]	±0	<0.0051	±0
Co	<0.002[1]	±0	N/A	N/A
Cr	0.007	±0.0082	0.00715	±0.00215
Cu	0.0045	±0.00129	<0.17[1]	±0
Fe	0.222	±0.229	<0.05[1]	±0
Pb	0.00975	±0.0035	<0.01[1]	±0
Mg	24.77	±3.29	16.0	±0
Mn	0.043	±0.0329	<0.05[1]	±0
Mo	<0.003[1]	±0	<0.02[1]	±0
Ni	<0.002[1]	±0	<0.005[1]	±0
Ag	<0.003[1]	±0	N/A	N/A
Sr	0.206	±0.00837	0.235	±0.005
Sn	<0.003[1]	±0	<0.05[1]	±0
V	0.0025	±0.0005	<0.005[1]	±0
Zn	0.0085	±0.0037	<0.05[1]	±0

[1] Detection Limit.

Table 4. ICP SCAN VALUES FOR WATER SAMPLES FROM CHOLLA LAKE, ARIZONA.

CONCENTRATION (ppm) (N=16)					
	MEAN	±STDEV		MEAN	±STDEV
A	1.636*	1.635	Pb	0.01081*	0.00429
Sb	<0.0300[1]	0.00000	Mg	83.69*	10.69
Ba	0.12788*	0.01538	Mn	0.01794*	0.01597
Be	<0.0010[1]	0.00000	Mo	0.00375	0.00124
B	0.21062*	0.02621	Ni	0.00238	0.00089
Cd	<0.0010[1]	0.00000	Ag	0.00306	0.00025
Co	0.00231	0.00125	Sr	1.1204*	0.1120
Cr	0.00788	0.00159	Sn	<0.0300[1]	0.00000
Cu	0.02306*	0.01827	V	0.01106*	0.00226
Fe	0.775*	0.741	Zn	0.01156*	0.00239

[1] Detection limit.

* Levels of Al, Cu, Fe, Mn, and Zn were higher in unfiltered samples (P<0.001), levels of Ba, Pb and Sr were higher at site #3 (P=0,005), and levels of Al, Ba, B, Cu, Fe, Mn, Sr, and V were higher in Cholla Lake when compared to Clear Creek (0.002 < P < 0.03).

Sediment Analysis

Arsenic levels were significantly lower at site No. 2 within Cholla Lake ($p = 0.004$) but higher in Clear Creek Reservoir when compared to Cholla Lake ($p = 0.05$). There was no difference in Hg or Se content between transects in Cholla Lake but levels of Se were higher in Cholla Lake when compared to Clear Creek. Both of these analytes were near or below detection levels in sediment from Clear Creek (Table 5) so statistical comparison was not done.

ICP results from sediment samples varied among transects within Cholla Lake (Table 6) with levels of Sr and Zn higher at site A, Mg and Mn higher at site No. 1, and B, Ni, Cr, Fe, and V higher at site No. 3 ($0.001 < p < 0.05$). Levels of Ba, Be, B, Fe, Mn, Sr, and V were significantly higher ($p = 0.05$) in Cholla Lake when compared with Clear Creek (Table 7).

The only invertebrates found in Cholla Lake were Chironomidae and <u>corbicula</u> <u>sp.</u> (table 8). In the hot pond, Chironomidae had an average density of 200/m^2. In the cold pond, <u>corbicula</u> <u>sp.</u> were found at sites 1 and 3 (100/m^2 and 20/m^2, respectively), and Chironomidae were found at sites 2 and 3 (100/m^2 and 200/m^2, respectively). No live gastropods were found, but many sediment samples

Table 5. ATOMIC ABSORPTION FOR SEDIMENT SAMPLES FROM CHOLLA LAKE AND CLEAR CREEK RESERVOIR, AZ. Reported in ppm (dry weight).

	CHOLLA LAKE (N = 8)		**CLEAR CREEK RES.** (N = 2)	
	MEAN	STDEV	MEAN	STDEV
As	1.3829*	0.2727	4.395*	0.318
Hg	0.02095*	0.00269	0.02140*	0.00198
Se	0.5529	0.2511	<0.300[1]	0.00000

[1] Detection limit.

* Levels of As were higher in Clear Creek Reservoir ($P = 0.05$), and at site #2 ($P = 0.004$) in Cholla Lake. Greater than 50% of the reported values for Hg were at, or below, detection limits in both lakes.

Table 6. ICP RESULTS FOR SEDIMENT SAMPLES FROM CHOLLA LAKE, ARIZONA. Reported in ppm (dry weight).

	CONCENTRATION (N=8)			CONCENTRATION (N=8)	
	MEAN	±STDEV		MEAN	±STDEV
Al	36550.0	8389.0	Pb	23.21	3.62
Sb	<60.00[1]	0.000	Mg*	8494.0	3183.0
Ba	337.5	40.5	Mn*	415.9	70.5
Be	1.3275	0.1295	Mo	<8.00[1]	0.00
B*	44.17	7.14	Ni*	13.363	2.145
Cd	1.0137	0.0389	Ag	<12.00[1]	0.00
Co	17.150	1.358	Sr*	298.5	158.1
Cr*	25.01	3.58	Sn	<60.00[1]	0.00
Cu	54.2	46.0	V*	53.30	5.81
Fe*	19687.0	1883.0	Zn*	55.41	11.45

[1] Below detection.

* Levels of Sr and Zn were higher at site A, levels of Mg and Mn were higher at site #1, and levels of B, Ni, Cr, Fe, and V were higher at site #3. ($0.001 < P < 0.05$).

Table 7. ICP RESULTS FOR SEDIMENT SAMPLES FROM CLEAR CREEK RESERVOIR, ARIZONA. Reported in ppm (dry weight).

	CONCENTRATION (n= 2)				
	MEAN	STDEV		MEAN	STDEV
Al	31400.0	13435.0	Pb	19.25	9.97
Sb	<60.000[1]	0.0	Mg	6005.0	2270.0
Ba	226.00*	9.90	Mn	304.5*	55.9
Be	0.977*	0.146	Mo	<8.000[1]	0.0
B	28.45*	2.47	Ni	13.35	1.91
Cd	<1.0000[1]	0.0	Ag	<12.000[1]	0.0
Co	13.00	2.12	Sr	58.300*	1.131
Cr	28.70	2.69	Sn	<60.000[1]	0.0
Cu	10.49	2.99	V	42.25*	4.45
Fe	14250.0*	2192.0	Zn	41.35	7.71

[1] Detection limits.

* concentrations in Clear Creek were significantly lower than for those in Cholla Lake (P = 0.05).

Table 8. TOTAL NUMBER OF BENTHIC INVERTEBRES IN SEDIMENT SAMPLES FROM CHOLLA LAKE, ARIZONA.

	HOT POND	COLD POND 1	COLD POND 2	COLD POND 3
No. of dredges*	20	12	8	12
No. chironomidae	13	0	3	8
No. corbicula sp.	0	3	0	1

* area/dredge = 314.16 cm^2

from both the hot and cold ponds contained empty and broken gastropod shells.

Fish

Five fish species (769 individuals), in order of relative abundance (*Lepomis macrochirus*, *Ictalurus punctatus*, *Micropterus salmoides*, *Cyprinus carpio*, and *Notemigonus chrysoleucus*) were found in Cholla Lake (Table 9) . Rio Grande killifish was reported in 1975 (Blinn et al. 1975), but no specimens were collected during the summers of 1989 or 1990. There was no significant difference in either the mean weights or lengths of bluegill or channel catfish caught at different sites within Cholla Lake. The mean weight for channel catfish was 131.84 g. (±34.08) and mean total length was 264.62 mm (±25.25). The mean weight for bluegill was 47.96 g (±11.92) and mean total length was 139.44 (±11.32). Bluegill were in predominantly one length class (128-152mm, RSD = 80), as were channel catfish (204-305mm, RSD = 91). Proportional stock densities were 11% for bluegill and and 4% for channel catfish.

Stomach contents for channel catfish in both the hot and cold ponds were dominated by filamentous algae and plant detritus. Of the remaining identifiable items found in the catfish stomachs, ostracods (6.7-47%), plant seeds (7.8-26.7%), and terrestrial insects (3-27%) were most abundant. Few (< 7%) Chironomidae or corbicula were counted in stomachs. Stomach contents of bluegill taken in the hot pond consisted primarily of Chironomidae (14-91%), plant detritus (23%), terrestrial insects (21%), and ostracods (16-3%). Stomach contents of bluegill taken in the cold pond were dominated by cladocera sp.. Chironomidae (82-33%) and plant detritus (5%) were minor components of the stomach contents. The majority of the Chironomidae found in the stomachs of bluegill from both the hot and cold pond were emerging adults (71 and 83%, respectively). Stomach contents of carp in both the hot and cold ponds consisted mostly of detritus and corbicula sp.. One largemouth bass contained a small channel catfish and a small bluegill (both <8mm in total length). All other bass stomachs were empty.

Scales taken from bluegill lacked distinct annuli so fish age could not be calculated.

Atomic absorption (Table 10) or ICP analyses (Table 11) did not show significant differences in the concentrations of inorganic constituents in the whole body tissue samples of fish from within Cholla Lake, except Se which was higher in bluegills relative to channel

Table 9. POPULATION CHARACTERISTICS OF FISH FROM CHOLLA LAKE, ARIZONA.

POPULATION CHARACTERISTICS	SAMPLE SITES			
	hot pond	**1**	**2**	**3**
Total # Fish Caught[1]	139	126	187	228
% Bluegill	77	49	74	85
% Channel catfish	21	42	22	11
% Carp	2	7	3	3
% Largemouth bass	0	2	<1	<1
% Golden shinners	0	0	0	<1
CHANNEL CATFISH[2]	(N=28)	(N=53)	(N=42)	(N=52)
Mean weight	128.14	140.58	131.26	142.27
(± stdev)	±46.99	±32.61	±38.26	±32.61
Mean total length	254.00	275.57	266.36	274.19
(± stdev)	±47.09	±20.06	±20.02	±19.46
BLUEGILL[2]	(N=214)	(N=62)	(N=138)	(N=193)
Mean weight	44.82	46.26	47.01	46.48
(±stdev)	±5.843	±10.34	±11.08	±9.186
Mean total length	133.95	140.03	139.51	140.23
(±stdev)	±6.73	±10.44	±11.08	±9.30

[1] Fish caught in 1990 only.
[2] Combined 1989 and 1990 catches.

Table 10. ATOMIC ABSORPTION VALUES FOR FISH TISSUE SAMPLES FROM CHOLLA LAKE, ARIZONA. Reported in ug/g (dry wt)

	BLUEGILL (N = 12)		CHANNEL CATFISH (N = 12)	
	MEAN	**STDEV**	**MEAN**	**STDEV**
As	<0.300	0.00000	0.3532	0.0764
Hg	0.02866	0.01453	0.02556	0.01426
Se	6.629**	0.679	5.164**	0.694

** Value significantly higher than for same species in Clear Creek Reservoir (P= 0.01).

Table 11. ICP SCAN ANALYSIS OF FISH TISSUE SAMPLES FROM CHOLLA LAKE, AZ. Reported in ppm (dry weight).

	CHANNEL CATFISH (N = 12)		BLUEGILL (N = 12)	
	MEAN	STDEV	MEAN	STDEV
Al	1332.0*[A]	1012.0	67.7	92.8
Sb	4.500	0.00	4.500	0.00
Ba	28.31[A]	11.26	8.171	2.613
Be	0.07292	0.01010	0.0700	0.00
B	6.026	1.827	5.192	1.066
Cd	0.11125	0.02351	0.100	0.00
Co	0.933	0.416	0.500	0.00
Cr	18.57[A]	17.95	7.30	17.83
Cu	9.17*[A]	3.83	2.178	1.036
Fe	861.0*[A]	421.0	100.1	144.3
Pb	1.583	0.798	1.428	1.257
Mg	3149.0*	535.0	2949.0	829.0
Mn	25.39[A]	10.67	10.87*	4.68
Mo	1.00	0.00	1.00	0.00
Ni	6.89	6.48	2.66	6.44
Ag	4.00	0.00	4.00	0.00
Sr	288.9[A]	45.7	430.6	200.3
Sn	5.00	0.00	5.00	0.00
V	1.929*[A]	0.643	0.2830	0.1312
Zn	129.33*[A]	11.98	115.70	30.60

* Levels of Al, Cr, Cu, Fe, Mg, V and Zn were higher in channel catfish and Mn was higher in bluegill collected from Cholla Lake.

[A] Values in Cholla Lake were higher for channel catfish than for bluegill (P = 0.001).

catfish. Levels of Se were significantly higher ($p = 0.01$) in fish tissue samples from Cholla Lake when compared to Clear Creek (Tables 10 and 12). Levels of Al, Cr, Cu, Fe, Mg, V, and Z were higher in channel catfish tissue and Mn was higher in bluegill tissue samples from Cholla Lake when compared with Clear Creek Reservoir (Table 13). Within Cholla Lake, levels of Al, Ba, Cr, Cu, Fe, Mn, Sr, V, and Zn were also Significantly higher in catfish tissue when compared to bluegill tissue ($p < 0.001$).

Physico-chemical characteristics

Average surface water temperatures within Cholla Lake varied significantly ($p < 0.001$) with hotter temperatures occuring in the hot pond and the coolest temperatures occuring near the plant intake. However, the average temperature in transect No.2 (27.5 C) did not differ from that in No.1. Temperatures in the hot pond (site A) averaged 33 C and temperatures at site No.3 averaged 25 C during the summer months. Average surface temperatures were significantly higher ($P < 0.05$) than bottom temperatures at transects No.1 and No.3 (Table 14), but there was no difference between surface and bottom temperatures at transects A and No.2.

Table 12. ATOMIC ABSORPTION VALUES FOR FISH TISSUE SAMPLES FROM CLEAR CREEK RESERVOIR, ARIZONA. (Reported in ug/g (dry weight).

	BLUEGILL (N = 3)		CHANNEL CATFISH (N = 3)	
	MEAN	**STDEV**	**MEAN**	**STDEV**
As	<0.3000	0.0000	0.3153	0.0266
Hg	0.277	0.233	0.0792	0.0544
Se	3.91	2.77	1.4200	0.0700

Table 13. ICP SCAN ANALYSIS OF FISH TISSUE SAMPLES TAKEN FROM CLEAR CREEK RESERVOIR, ARIZONA.
Reported in ppm (dry weight).

	CHANNEL CATFISH (N = 3)		BLUEGILL (N= 3)	
	MEAN	STDEV	MEAN	STDEV
Al	101.4	60.9	47.7	50.9
Sb	<4.500	0.00	<4.500	0.00
Ba	39.9	29.2	11.11	3.60
Be	<0.0700	0.00	<0.0700	0.00
B	3.94	2.40	4.723	0.510
Cd	0.10733	0.01270	0.10633	0.01097
Co	0.5263	0.0456	<0.500	0.00
Cr	9.78	2.93	2.413	0.464
Cu	1.504	0.733	1.840	0.617
Fe	195.3	38.9	75.3	34.7
Pb	1.0300	0.0520	<1.00	0.00
Mg	1412.0	764.0	1703.0	1451.0
Mn	20.18	11.59	27.57	11.00
Mo	<1.00	0.00	<1.00	0.00
Ni	4.79	2.37	<0.800	0.00
Ag	<4.00	0.00	<4.00	0.00
S	<4.00	0.00	<4.00	0.00
Sn	<5.00	0.00	<5.00	0.00
V	0.506	0.222	0.340	0.197
Zn	75.4	43.5	141.7	18.9

Table 14. AVERAGE SUMMER WATER TEMPERURES AND SECCHI DISK READINGS FOR CHOLLA LAKE, ARIZONA.

	TEMPERATURE				SECCHI DISK	
	SURFACE (°C)		BOTTOM (°C)		CM	
Site A	29.353*	±1.222	-	-	39.93*	±7.32
Site 1	27.483*	±1.397	25.975*	±1.177	46.083*	±2.843
Site 2	27.513	±1.185	-	-	51.25	±7.56
Site 3	24.273*	±1.103	23.555*	±1.024	52.50	±4.58

* Water temperature was significantly higher and transparancy lower at site A whereas temperature was lowest and transparancy highest at site 3. Bottom water temperatures were significantly lower than surface temperatures at sites 1 and 3 (P = 0.05).

Secchi disk readings in Cholla Lake varied significantly ($p < 0.001$) by transect. The hot pond had the lowest reading while transects 2 and 3, in the cold pond, had the highest.

The average pH in Cholla Lake was 8.92. There were no significant differences in pH throughout the lake. Conductivity averaged 4,500 umho/cm (±1,394.86, $n = 12$) and was relatively constant throughout the lake. Average conductivity was recorded as 2,200 umoh/cm by the Cholla Power Generating Station environmental division (John Rosnovack 1991, Arizona Public Service, Pers. Com.)

DISCUSSION

Blinn et al. (1974), and Dames and Moore (1973), predicted that the temperature increases resulting from the 1977 addition of 250 MW generators to the Cholla Power Generating Station would alter the diversity of biota, as well as densities, in Cholla Lake. These predictions have proven to be true.

Macrophytes have declined from extensive beds of four species in 1976 (Blinn et al. 1976) to the limited occurrence of one species (<u>Potomageton</u> <u>filiformis</u>) in 1989-90. Chironomid densities have declined from 6.75 x $10^3/m^2$ to 0.2 x $10^3/m^2$ over the same period.

Fish populations have also changed since to 1976. By 1985 there were changes in the composition of standing stocks of sport fish as well as reductions in secondary production, macrobenthos and zooplankton (Novy and Clay 1986).

Between 1976 and 1986 PSD's for bluegill declined from 30-50% (Blinn et al. 1976) to 11% with the majority of the fish (RSD = 57) in the 128-152 mm range (Novy and Clay 1986). The bluegill PSD in 1989-1990 was 11% and the majority of fish (RSD = 80) were still in the 128-152 mm range. Novy and Clay (1986) caught many small fish in

1985 but I caught no fish in the 77-102 mm range and very few (RSD = 5.5) in the 103-127 mm range.

Average weight of bluegill decreased 23% between 1976 and 1985 (Novy and Clay 1986) but increased 64% between 1986 and 1990. This increase does not represent better factors but the absence of small bluegill. Carlander (1969) reported representative bluegill condition factors of 2.0 to 4.0. Novy and Clay (1986) reported an average condition factor of 1.23 in 1986. In 1989-90 the condition factor for bluegill ranged from 0.4 to 2.5 and averaged 1.72 (±0.19). Bluegill still are in poor condition in Cholla Lake.

Between 1976 and 1985 PSD's for channel catfish declined from 60% (Blinn et al. 1976) to 10%, with the majority of catfish (RSD = 90.9) in the 204-305 mm range (Novy and Clay 1986). The majority of catfish were in the 204-305 mm range (RSD = 91) but PSD had declined to 4%. No catfish in the larger size ranges reported by Novy and Clay (1986) were taken in our study.

Average weight of catfish decreased 76% between 1976 (Blinn et al. 1976) and 1986 and by 19% between 1986 (Novy and Clay 1986) and 1989-90. Current condition factors range from 0.64 to 0.94 and average 0.70 (±0.098). Average condition factors for channel catfish of 1.7 have been reported in a warmwater fishery given optimum forage conditions (Perry and Avault 1969). Catfish seem to be in poor condition in Cholla Lake.

I did not catch enough largemouth bass to calculate average weight or length, or other population indices such as PSD or RSD. This lack of catch could be a sampling artifact, but Blinn et al. (1974) was able to catch largemouth bass with the same type of gill nets I used.

Bluegill and channel catfish are abundant in Cholla Lake and are successfully reproducing; no sport fish have been stocked since 1972 (Novy and Clay 1986). However, I caught no small fish (<110 mm for bluegill and <211 mm for catfish) in 1989-90. Absence of small fish in our catch could be a sampling artifact because of the use of gill nets, but baited minnow traps and seines also failed to catch small fish. Some small fish did occur in the lake; I found gravid catfish and bluegill and one bass stomach contained young fish. However, my data suggest that young fish were not abundant.

There are several possible explanations of the low condition factors and lack of reproduction observed in Cholla Lake. Reproduction may occur sporadically and high year class abundance may cause stunting. High exploitation of the few fish that achieve catchable size may result in the appearance of a limited number of size classes. While I can not entirely discount these possibilities, it appears probable that both temperature and environmental conditions in Cholla Lake may also hinder fish reproduction and growth. Temperatures in Cholla Lake are close to the tolerance limits of 38 C for channel catfish fry (Moss and Scott 1961) and 34 C for bluegill embryos (Banner and Van Arman 1973).

Growth, survival, and successful reproduction of fish could also be compromised by the limited food base. There has been a decrease in the density of benthic organisms from 1976 to present.

Another possibility is that the levels of inorganic elements affect fish populations. Elements such as arsenic (As), cadmium (Cd), copper (Cu), Iron (Fe), lead (Pb), manganese (Mn), mercury (Hg), nickel (Ni), selenium (Se), vanadium (V), and zinc (Zn) sometimes accumulate near coal-fired plants (Torrey 1978, Alabaster and Lloyd 1982, Hilton and Bettger 1988). They are considered hazardous because of their persistence in the environment, high toxicity and tendency to bioaccumulate (Atchison et al. 1987). Even at sublethal levels, these elements cause difficulties with osmoregulation. Cadmium also causes spinal deformities and impaired development of ova (McKee and Wolf 1963, Eisler 1971, Bilinski and Jonas 1973, Clearly and Coleman 1974). Six of these elements (As, Cu, Fe, Mn, Se, and V) were at elevated levels in either the water or sediment of Cholla Lake and five (Cd, Cu, Pb, Se, and Zn) were above National Contaminant Biomonitoring Program means in fish tissue (Schmitt and Brumbaugh 1990). In the United States, coal combustion at coal-fired power plants is thought to be the principal emission source for five of these six elements (Bowen 1966, Nelson 1977, Alabaster and Lloyd 1982, Lemly 1985, King, U.S.F.W.S, pers. comm.). Copper, the sixth element, is commonly introduced as copper sulfate a common anti-fouling agent used to control the undesirable growth of plankton (McKee and Wolf 1963). However, I do not know if copper sulfate is the specific anti-fouling agent used at Cholla Lake. Although the levels of these elements were elevated in Cholla Lake, they were below water quality levels set by the State of Arizona[1] (L. Lawson, AZDEQ, pers. comm.) and below known acute toxicity levels.

Coal-fueled power plants in the U.S. emit about

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[1]The Arizona water quality standards are currently under revision per the triennial review process (L. Lawson pers. comm., AZDEQ, 1990). The water quality criterion reported in this thesis are, therefore, subject to change.

3,000 tons of arsenic per year (Nelson 1977). Arsenic is elevated in water samples taken from Cholla Lake in comparison to Clear Creek Reservoir but both is well below both Arizona and EPA quality criteria. Current State of Arizona water quality standards for As are 0.05 ppm (filtered). U.S. EPA criteria are 0.44 ppm (as trivalent As) (USEPA 1980). Sediment values for As in Cholla Lake are 395 times higher than the values in water but they are lower than those in Clear Creek Reservoir which are approximately 2000 times higher than values in water. High sediment values of As would be expected in Clear Creek Reservoir because of low solubility in natural waters (NAS 1977, U.S. EPA 1976). The cold water of Clear Creek Reservoir may cause As compounds to precipitate while the heated water of Cholla Lake increases solubility leaving more As compounds in solution.

The current Arizona water quality standards for the protection of aquatic life and wildlife for Cd are 0.01 ppm. Cadmium levels are well below this value in Cholla Lake (<0.001 ppm), but levels in catfish tissue collected at Cholla Lake are above those reported by the National Contaminant Biomonitoring Program (NCBP). Cadmium in catfish tissue from Clear Creek is just at NCBP levels. Cadmium accumulates in the gills, liver, and kidneys of fish and is thought to impair osmoregulatory functions (Clearley and Coleman 1974). Acute toxicity of Cd is increased with an increase in temperature and a reduction of dissolved oxygen (Eisler 1971). Sublethal effects of Cd include spinal deformities and impaired development of ova. Acclimation to Cd occurs during the embryonic stage increasing resistance in the young, but Alabaster and Lloyd (1982) reported 100% egg mortality occurring at 0.002 ppm, aqueous.

The current Arizona water quality standard for copper for the protection of fish and wildlife is 0.05 ppm (filtered). Levels in Cholla Lake are below state standards but are high in comparison to those at Clear Creek Reservoir. Levels for both bluegill and catfish tissue in Cholla Lake are above NCBP levels and catfish were above the NCBP 85th percentile level. Little is known about the mode of action of copper on fish but gill function may be compromised (Bilinski and Jonas 1973). Toxicity of Cu is increased with a reduction in dissolved oxygen, and by interactions with other metals, especially Zn (Brown and Dalton 1970). The early larval stages of some fish tend to be sensitive to Cu and growth and survival of bluegill larvae are reduced when they are exposed 0.04-0.07 ppm (at 13-28 C) (Alabaster and Lloyd 1982).

The current Arizona water quality standards for lead is 0.05 ppm (filtered). Levels in water collected at Cholla Lake are well below this standard, however, levels in sediment are high (23.21 ppm). Levels in tissue of both bluegill and catfish for Pb are above the national means and the 85th percentile reported by the NCBP. However, levels in catfish tissue from Clear Creek Reservoir are also above the NCBP means. Lead impairs osmoregulation at chronic exposure levels as low as 1 ppm, aqueous (Mckee and Wolf). Selenium is another element that can become toxic at high levels. Even at low (0.005 ppm) concentrations, Se will accumulate and become magnified through the food chain (Lemly 1982); particularly being concentrated in the visceral tissues of fish (Gillespie et al. 1988).

The current Arizona water quality standard for the protection of aquatic life for selenium is 0.01 ppm (L. Lawson pers. comm., AZDEQ, 1990) but a more stringent maximum allowable level 0.005 ppm has been proposed by Lemly (1985) for filtered samples. Significantly elevated tissue levels have been seen in fish chronically exposed to levels as low as 0.01 ppm (Lemly 1982). Levels in water samples from all study sites were below these limits but Cholla Lake samples approached the more stringent 0.005 ppm limit (0.0047 ppm ±0.001). Concentrations in the tissues of both bluegill and catfish from Cholla Lake were above the NCBP national means as well as the reported 85th percentile (Schmitt and Brumbaugh 1990). Selenium acts particularly on the ovaries and has been shown to inhibit fish reproduction (Gillespie et al. 1988, Baumann and Gillespie 1986).

Selenium also effects tissues associated with detoxification (liver) and elimination (kidney) (Finley 1985). Fish exposed to chronic low-level selenium show swollen gill lamellae, focal glomerulonephritis, and low condition factors (Sorensen et al. 1984, Sorenson and Bauer 1984).

The current Arizona water quality standard for the protection of aquatic life for zinc is 0.50 ppm, filtered samples (L. Lawson pers. comm., AZDEQ, 1990). Although levels of Zn in Cholla Lake were elevated in comparison to Clear Creek Reservoir, they were well below the 0.50 ppm level. Zinc levels in fish tissues was elevated, however, and was above the NCBP reported national mean in both lakes. The concentrations in fish tissue from Cholla Lake were the highest and approached the reported 85th percentile level (Schmitt and Brumbaugh 1990).

Zinc is an essential trace element in living organisms and is used during nucleic acid synthesis as well as in the production of many enzymes. It is a common natural element (Alabaster and Lloyd 1982), however, anthropogenic input is considerable and about 240 metric tons/year enter the aquatic environment of southern California via atmospheric (Hodge et al. 1978) Background levels of zinc in natural surface waters are highly variable and range from nanograms per liter to >0.2 mg/l (Martin et al. 1980, Alabaster and Lloyd 1982).

Fish that were exposed to chronicly toxic levels of zinc showed poorly developed liver blood vessels, distended kidney tubules and glomeruli, mesenteries devoid of fat, and underdeveloped gonads. Further exposure resulted in large vacuoles in the liver, underdeveloped spleens, and granulocytes in the heart muscle. Although acute toxicity is manifest through gill damage, this was not seen in fish exposed to chronically toxic levels of zinc (Martin et al. 1980)

Factors affecting acutely the toxicity of zinc include temperature, dissolved oxygen, pH, organic matter, and suspended solids. Increases in temperature and decreases in dissolved oxygen increase the toxicity of Zn. While an increase in suspended solids tends to reduce Zn toxicity, in hard water with a pH of 8 or greater, the benefit of suspended solids is nullified (Lloyd 1960). In Cholla Lake, levels of Zn in the water are low, but, given the interactive affects of the above varibles, there is potential for decreased fish vigor.

Zinc can have a direct toxicity to aquatic life with a lethal threshold concentration being reported as 570 ppb (0.57 ppm), but more commonly, sublethal levels of zinc will affect fish along with copper or other metals (Alabaster and Lloyd 1982, Sprague 1968). The joint action of Zn and Cu is additive in hard water and the 2-day LC50 for the combination can be predicted by summing the fractional 2-day LC50 values for each metal (Lloyd 1960). a summation of Cholla Lake water concentrations for Zn and Cu may give a more representative picture of the potential toxicity of these two metals.

The combined affects of all the inorganic elements found in Cholla Lake are difficult to determine. The affects may be direct or incidental if a portion of the food supply is destroyed through poisoning. All the elements listed by the National Contaminants Biomonitoring Program affect fish directly, even at low levels, by producing stress. This stress can be caused through osmoregulatory malfunction and may result in decreased fecundity, reduced overall condition, and liver and kidney pathologies, not inclusive. Levels that are well below chronic toxicity levels for adults may be toxic for eggs and fry. Sub-lethal levels of metals may also alter fish behaviors. Locomotor activities of fish can be affected through altering sensory perception and reducing responses to normal olfactory cues associated with such activities as feeding. Alterations in free locomotor activity (manifested as hypo- or hyperactivity), or in locomotor components such as turning frequency or angular orientation may also occur (Atchison et al., 1987). Reproductive behavior is also affected and Benoit et al. (1976), have found that brook char (Salvelinus fontinalis) did not become hyperactive during prespawning exposure to Cd. Similar effects have been seen in other fish with Cd as low as 0.043 ppm along with Zn as low as 0.73 ppm (Spehar et al. 1978).

Although fish are still at least sporadically successfully recruiting in Cholla Lake, there is evidence that the lake is now less amenable to the maintenance of a sport fishery than it was in 1976. Water temperatures do not exceed, but approach, lethal limits for fry and juveniles. Fish food organisms have declined in abundance and condition factors and average size of fish has also declined. Inorganic element levels do not exceed existing standards but they approach levels that may ultimately impair fish reproduction.

Reservoirs for power plant cooling water provide important recreational fisheries, but conditions that are unique to these water bodies pose special management problems. Some of these problems include maximum temperatures at or near the upper lethal limits for warmwater fishes and levels of elements that may approach toxic or reproductive impairment levels (Morgan and Stauffer 1980). Both of these factors may be affecting Cholla Lake and be responsible for the decline in fish condition, size and recruitment.

CONCLUSION

Predicting future trends in the plant and animal communitites of Cholla Lake is difficult. Although, if current management practices, as well as current temperature regimes, persist the lake will most likely continue to decline as a fishery. The quality of Cholla Lake insofar as a recreational fishery could be improved. Reducing water temperature along with increasing dissolved oxygen could be accomplished by passing the discharged water through a series of baffled runs before it reaches the lake. Artificial structures in the lake would not only increase available habitat but may also help to decrease turbidity. However, one aspect of Cholla Lake that will, most likely, not be changed is its primary purpose as a cooling reservoir for the Cholla Power Plant. Active management of Cholla Lake as a fishery may not be compatible, or feasible, with this primary purpose. Any steps taken to improve the fishery would require much discussion between the principle managing agencies.

Currently some local people fish Cholla Lake regularly, perhaps for subsistence. My study did not, nor was it intended to, address any human health concerns regarding levels of elements in edible fish portions. There is also a breeding population of black crowned night herons (Nycticorax nycticorax naevius) who, along with their offspring, feed primarily on the fish in Cholla Lake. Again, this study was not intended to assess effects of potential toxicity to these birds. In the future it would be prudent to monitor levels of potential toxicants in fish tissue for the protection of both humans and wildlife. Monitoring should include chemical analysis of edible portions of fish tissue as well as whole body samples.

Along with this, yearly observations on the heron rookery should be made to determine if any effects, such as reproductive impairement, are occurring.

APPENDICES

APPENDIX A

Laboratory Protocols for Water, Sediment,

and Tissue Analysis.

Laboratory Protocols for Water, Sediment, and Tissue Analysis. Performed by Research Triangle Institute, Research Triangle Park, North Carolina.

WATER SAMPLE PREPARATION

Preconcentration Digestion for Inductively Coupled Plasma Emission (ICP) Measurement

Using a CEM microwave oven, 50 mL of water sample was heated in a capped 120 mL Teflon vessel in the presence of 4 mL of Baker Instra-Analyzed nitric acid and 1 mL perchloric acid for 3 minutes at 120 watts, three minutes at 300 watts, and 35 minutes at 450 watts. The vessel contents were then allowed to cool and the cap removed and rinsed carefully with 3 mL of HNO_3 adding the rinsings with the vessel contents. The uncapped vessel was then returned to the microwave oven and heated until the vessel contents are less than 1 mL in volume. The contents were carefully rinsed with laboratory pure water into a 10 mL glass volumetric vessel and made to volume with additional laboratory pure water. ICP measurements were then made using a Leeman Labs Plasma Spec I sequential spectrometer.

Digestion for Graphite Furnace Atomic Absorption (GFAA) Measurement

Using a CEM microwave oven, 50 mL of water sample was heated in a capped 120 mL Teflon vessel in the presence of 5 mL of Baker Instra-Analyzed nitric acid for 15 minutes at 300 watts. The residue was then diluted to 100 mL with laboratory pure water. GFAA measurements were then made using a Perkin Elmer Zeeman 3030 atomic absorption spectrophotometer with an HGA-600 graphite furnace and an AS-60 autosampler.

Digestion for Hg Measurement by Cold Vapor Atomic Absorption(CVAA)

Ten mL of water sample was refluxed for 2 hours in 10 mL HNO_3 (Baker Instra-Analyzed) and diluted to 50 mL with 1% HCL. Hg measurements were then conducted using $SnCl_4$ as the reducing agent. An Instrumentation Laboratories Model 251 AA spectrophotometer was employed.

SEDIMENT ANALYSIS PREPARATION

Homogenization

Following freeze drying, samples were ground to approximately 100 mesh using a glass mortar and pestle.

Digestion for Inductively Coupled Plasma Emission (ICP) Measurement

Some 0.25 to 0.5 g of sediment was placed in 120 mL Teflon microwave vessel. One mL each of HCL, HF, and $HCLO_4$, and 10 mL HNO_3 were added to the vessel. the vessel was then capped according to the manufacturer's instructions and was heated in a CEM microwave oven for 2 minutes at 120 watts, 3 minutes at 180 watts, and 10 minutes at 600 watts. The resulting residue was diluted to 100 mL with 5% HCL. This solution was then filtered through Whatman 41 filter paper prior to ICP measurement. An HF resistance torch tip was used for these digests during the ICP measurement.

Digestion for Graphite Furnace Atomic Absorption (GFAA) Measurement

Using a CEM microwave oven, 0.25 to 0.5 g of sediment were heated in a capped 120 mL Teflon vessel in the presence of 5 mL of Baker Instra-Analyzed nitric acid for 3 minutes at 120 watts, 3 minutes at 300 watts, and 15 minutes at 450 watts. The residue was then diluted to 50 mL with laboratory pure water.

Digestion for Hg Measurement by Cold Vapor Atomic Absorption(CVAA)

Some 0.25 to 0.5 g of sample was refluxed for 2 hours in 10 mL HNO_3 (Baker Instra-Analyzed) and diluted to 50 mL with 1% HCL.

TISSUE SAMPLE PREPARATION

Homogenization

Homogenization was performed using a Kitchen Aid food processor. Portions were then freeze dried for determination of moisture content and subsequent acid digestion.

Preconcentration Digestion of Inductively Coupled Plasma Emission (ICP) Measurement

Using a CEM microwave oven, 0.5 g of freeze dried tissue are heated in a capped 120 mL Teflon vessel in the presence of 5 mL of Baker Instra-Analyzed nitric acid for 3 minutes at 120 watts, 3 minutes at 300 watts, and 35 minutes at 450 watts. The vessel contents are then allowed to cool and the cap is removed and rinsed carefully with 3 mL of HNO_3 adding the rinsings with the vessel contents. The uncapped vessel is then returned to the microwave oven and heated until the vessel contents are less than 1 mL in volume. The contents are carefully rinsed with laboratory pure water into a 10 mL glass volumetric vessel and made to volume with additional laboratory pure water. The flask contents are then immediately transferred to a clean plastic centrifuge or auto sampler tube and centrifuged for 1 minute to precipitate the suspended matter.

Digestion for ICP Measurement

Using a CEM microwave oven, 0.25 to 0.5 g of freeze dried tissue were heated in a capped 120mL Teflon vessel in the presence of 5 mL of Baker Instra-Analyzed nitric acid for 3 minutes at 120 watts, 3 minutes at 300 watts, and 15 minutes at 450 watts. The residue was then diluted to 50 mL with 5% HCL.

Digestion for Graphite Furnace Atomic Absorption (GFAA) Measurement

Using a CEM microwave oven, 0.25 to 0.5 g of freeze dried tissue was heated in a capped 120 mL Teflon vessel in the presence of 5 mL of Baker Instra-Analyzed nitric acid for 3 minutes at 120 watts, 3 minutes at 300 watts, and 15 minutes at 450 watts. The residue was then diluted to 50 mL with laboratory pure water.

Digestion for Hg Measurement by Cold Vapor Atomic Absorption (CVAA)

Some 0.25 to 0.5 g of tissue was refluxed for two hours in 10 mL HNO_3 (Baker Instra-Analyzed) and diluted to 50 Ml with 1% HCL.

APPENDIX B

Current water quality standards

for the State of Arizona[1].

Parameter	Standard mg/l[2]
Arsenic (as AS)	0.05 dissolved
Copper (as Cu)	0.05 dissolved
Iron	No Standard
Lead (as Pb)	0.05 dissolved
Managanese (as Mn)	No standard
Selenium (as Se)	0.01 total
Vanadium	No Standard
Zinc (as Zn)	0.50 dissolved

[1] Lin Lawson, Arizona Department of Environmental Quality.

[2] These standards will be superseded by new standards at the end of the 1990 trienial review process.

National Contaminant Biomonitoring Program: Concentrations of Arsenic, Cadmium, Copper, Lead, Mercury, Selenium, and Zinc in U.S. Freshwater Fish, 1984[1]

	Geo. Mean	Maximum	85th percentile
As	0.14	1.5	0.27
Cd	0.03	0.22	0.05
Cu	0.65	23.1	1.0
Hg	0.10	0.37	0.17
Pb	0.11	4.88	0.22
Se	0.42	2.30	0.73
Zn	21.7	118.4	34.2

[1] Schmitt and Brumbaugh, 1990.

RELATIVE FREQUENCIES OF FISH SPECIES
CAUGHT IN CHOLLA LAKE, AZ.

	hot pond	**1**	**2**	**3**
total No. caught	139	126	187	228
% bluegill	77	49	74	85
% channel catfish	21	42	22	11
% carp	2	7	3	3
% largemouth bass	0	2	<1	<1
% golden shiners	0	0	0	<1

CATCH PER UNIT EFFORT (No. FISH/HR).
FOR EACH SPECIES AT EACH SITE
AND FOR EACH NET TYPE USED.

Site A

	Trammel Net No.1	Trammel Net No.2	Trammel Net No.3
catfish	1.76	2.93	3.14
bluegill	12.1	10.33	7.32
carp	1.62	0.35	0
bass	0	0	0

Site No.1

	Trammel Net No.1	Trammel Net No.2	Gill Net
catfish	6.3	5.6	1.95
bluegill	9	5.58	2.14
carp	1	0.23	0.97
bass	0	0.23	0

Site No.2

	Trammel Net No.1	Trammel Net No.2	Gill Net
catfish	7.2	3.2	1.5
bluegill	22.56	13.0	1
carp	0	0.49	0.5
bass	0	0.25	0

Site No.3

	Trammel Net No.1	Trammel Net No.2	Gill Net
catfish	0.81	4.98	1.9
bluegill	4.27	35.85	17.8
carp	0.81	0.25	0.94
bass	0	0	0
gld. shnnr	0	0	1.9

TOTAL RATIO ESTIMATORS (No. fish/Hr)

	Site A	Site No.1	Site No.2	Site No.3
catfish	1.72	4.26	3.35	2.6
bluegill	7.07	4.99	10.25	18.4
carp	0.55	0.72	0.39	0.60
bass	0	0.16	0.10	0
golden shinners	0	0	0	0.20

CONDITION FACTORS (K_{TL}) FOR FISH FROM CHOLLA LAKE, ARIZONA.

BLUEGILL

1974[1]	1975[1]	1976[1]	1986[2]	1990*
1.1-2.0	1.7-2.1	1.7-2.2	0.8-1.4	0.42-2.5

CHANNEL CATFISH

1974[1]	1975[1]	1976[1]	1986[2]	1990*
0.7-0.9	0.6-1.0	0.3-0.9	0.6-0.9	0.27-1.1

* average values:
Bluegill; 1.72 ±0.19
Channel catfish; 0.697 ±0.098

[1] from Blinn et al.

[2] from Novy and Clay

HISTOGRAMS OF COMBINED BLUEGILL WEIGHTS
AND LENGTHS FROM CHOLLA LAKE.
(N = 560)

```
Bluegill weights (g)
Each * represents 5 obs.

Midpoint   Count
   15.00       0
   20.00       4  *
   25.00       1  *
   30.00       5  *
   35.00      29  ******
   40.00     146  ******************************
   45.00     166  **********************************
   50.00      91  *******************
   55.00      40  ********
   60.00      30  ******
   65.00      11  ***
   70.00       9  **
   75.00       4  *
   80.00       5  *
   85.00       8  **
   90.00       6  **
   95.00       2  *
  100.00       1  *
  105.00       1  *
  110.00       1  *
```

HISTOGRAMS OF COMBINED BLUEGILL WEIGHTS
AND LENGTHS FROM CHOLLA LAKE.
(N = 560)

```
Bluegill lengths (mm)
Each * represents 5 obs.

Midpoint   Count
  100.00       0
  105.00       0
  110.00       4  *
  115.00       3  *
  120.00       7  **
  125.00      24  *****
  130.00      87  ******************
  135.00     158  ********************************
  140.00     134  ***************************
  145.00      59  ************
  150.00      24  *****
  155.00      21  *****
  160.00       9  **
  165.00      11  ***
  170.00       6  **
  175.00       8  **
  180.00       1  *
  185.00       2  *
  190.00       1  *
  195.00       0
  200.00       1  *
```

HISTOGRAMS OF COMBINED CHANNEL CATFISH WEIGHTS AND LENGTHS FROM CHOLLA LAKE, AZ. (N = 209)

Channel Catfish Weights (g)

Midpoint	Count	
45.00	0	
50.00	1	*
55.00	1	*
60.00	1	*
65.00	3	***
70.00	0	
75.00	0	
80.00	1	*
85.00	2	**
90.00	6	******
95.00	4	****
100.00	7	*******
105.00	12	************
110.00	13	*************
115.00	13	*************
120.00	17	*****************
125.00	18	******************
130.00	17	*****************
135.00	15	***************
140.00	12	************
145.00	8	********
150.00	11	***********
155.00	4	****
160.00	5	*****
165.00	5	*****
170.00	3	***
175.00	8	********
180.00	4	****
185.00	4	****
190.00	1	*
195.00	2	**
200.00	4	****
205.00	0	
210.00	1	*
215.00	0	
220.00	1	*
225.00	2	**
230.00	0	
235.00	1	*

HISTOGRAMS OF COMBINED CHANNEL CATFISH WEIGHTS
AND LENGTHS FROM CHOLLA LAKE, AZ (cont).
(N = 209)

Channel Catfish Lengths (mm)

Midpoint	Count	
195.00	1	*
200.00	0	
205.00	0	
210.00	1	*
215.00	1	*
220.00	0	
225.00	0	
230.00	2	**
235.00	6	******
240.00	9	*********
245.00	14	**************
250.00	18	******************
255.00	15	***************
260.00	26	**************************
265.00	21	*********************
270.00	20	********************
275.00	26	**************************
280.00	10	**********
285.00	12	************
290.00	8	********
295.00	2	**
300.00	2	**
305.00	4	****
310.00	2	**
315.00	3	***
320.00	3	***
325.00	1	*

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